

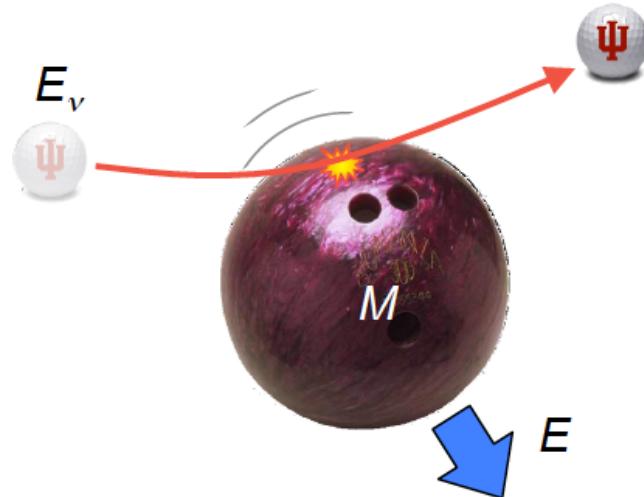
Thoughts on a Coherent Neutrino Scattering Program using LAr Detectors @ the BNB

Andrew Hime
Pacific Northwest National Laboratory

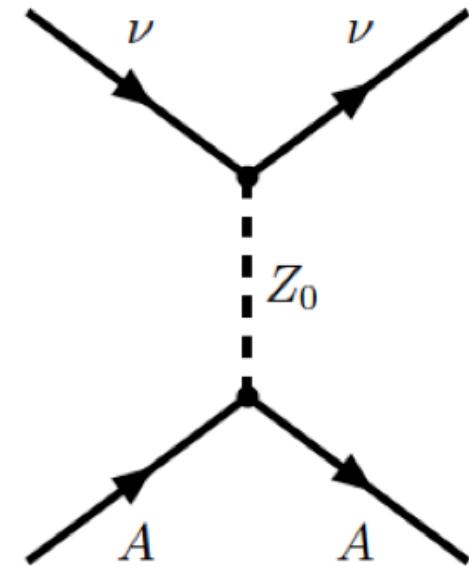
**Fermilab Neutrino Physics Seminar
Fermilab
February 26, 2015**



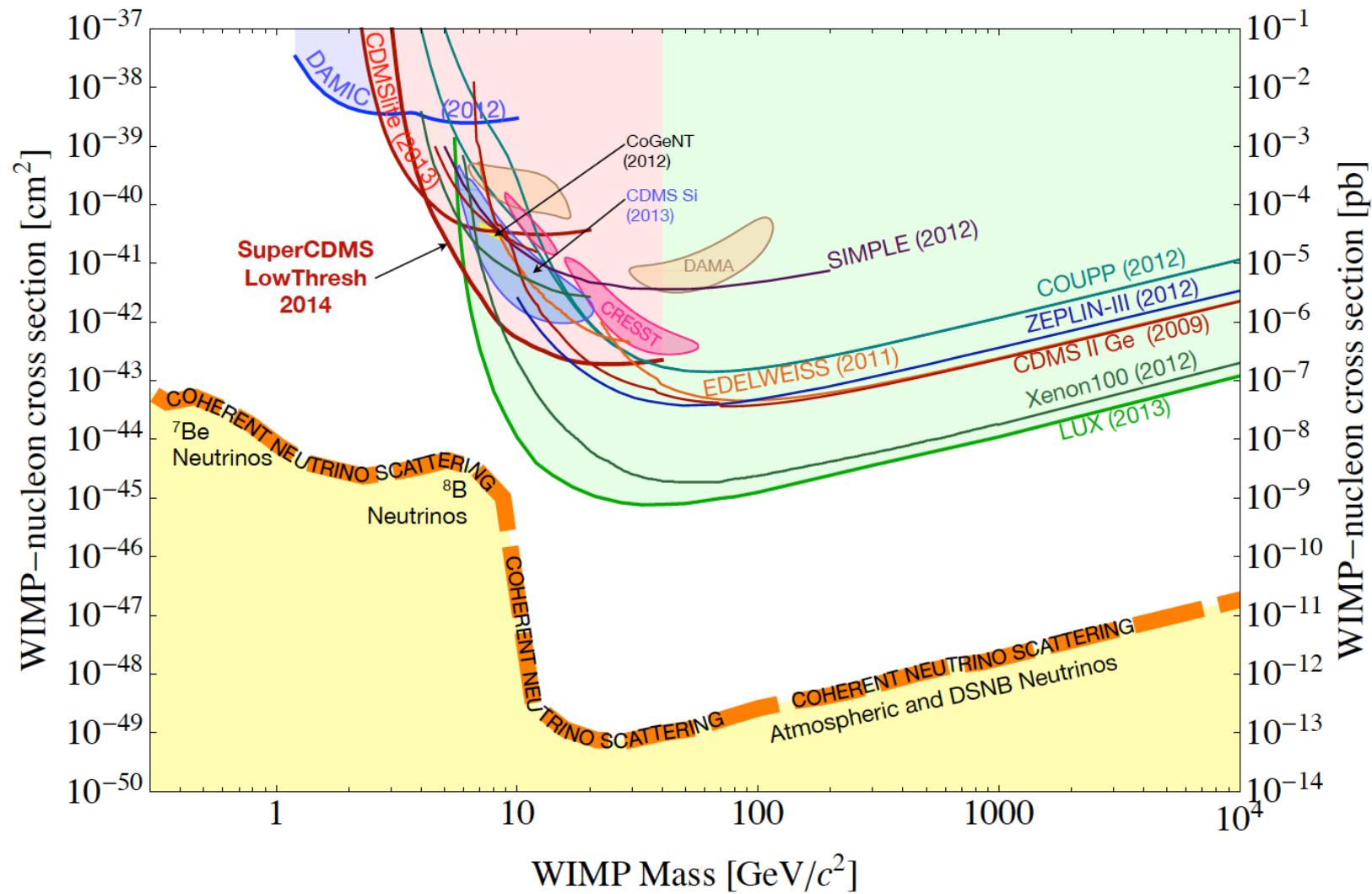
$$E_\nu \lesssim \frac{hc}{R_N} \cong 50 \text{ MeV}$$



$$E_r^{\max} \simeq \frac{2E_\nu^2}{M} \simeq 50 \text{ keV}$$



$$\frac{d\sigma}{dE} = \frac{G_F^2}{4\pi} \left[(1 - 4 \sin^2 \theta_w) Z - N \right]^2 M \left(1 - \frac{ME}{2E_\nu^2} \right) F(Q^2)^2$$



CLEAN for Dark Matter & Low-Energy Neutrinos

- LAr may be the only means to push sensitivity for high mass WIMPs into the background floor from coherent neutrino scattering.
- LXe cannot proceed beyond G2 due to a fundamental limit imposed by elastic scattering of pp -solar neutrinos. The superior PSD afforded by LAr avoids this limitation.
- A background-free LAr exposure of \sim 400 tonne-years is required to reach the background floor.
- A \sim 100 tonne LAr detector using UAr and an active neutron veto are basic requirements.
- Target exchange with LNe *in the same detector* might be vital in verifying a discovery.
- A LNe detector of this scale could *simultaneously* exploit the Sun as a precision source of neutrinos.
- Such a detector would also provide a unique target for Supernovae neutrinos.
- Monolithic detectors of LAr and LNe are ideal for studying and exploiting new physics frontiers using low-energy neutrinos that coherently scatter from nuclei.

PHYSICAL REVIEW D **89**, 072004 (2014)

A method for measuring coherent elastic neutrino-nucleus scattering at a far off-axis high-energy neutrino beam target

S. J. Brice,¹ R. L. Cooper,^{2,*} F. DeJongh,¹ A. Empl,³ L. M. Garrison,² A. Hime,⁴ E. Hungerford,³ T. Kobilarcik,¹ B. Loer,¹ C. Mariani,⁵ M. Mocko,⁴ G. Muhrer,⁴ R. Pattie,⁶ Z. Pavlovic,⁴ E. Ramberg,¹ K. Scholberg,⁷ R. Tayloe,² R. T. Thornton,² J. Yoo,¹ and A. Young⁶

¹*Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA*

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³*University of Houston, Houston, Texas 77204, USA*

⁴*Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

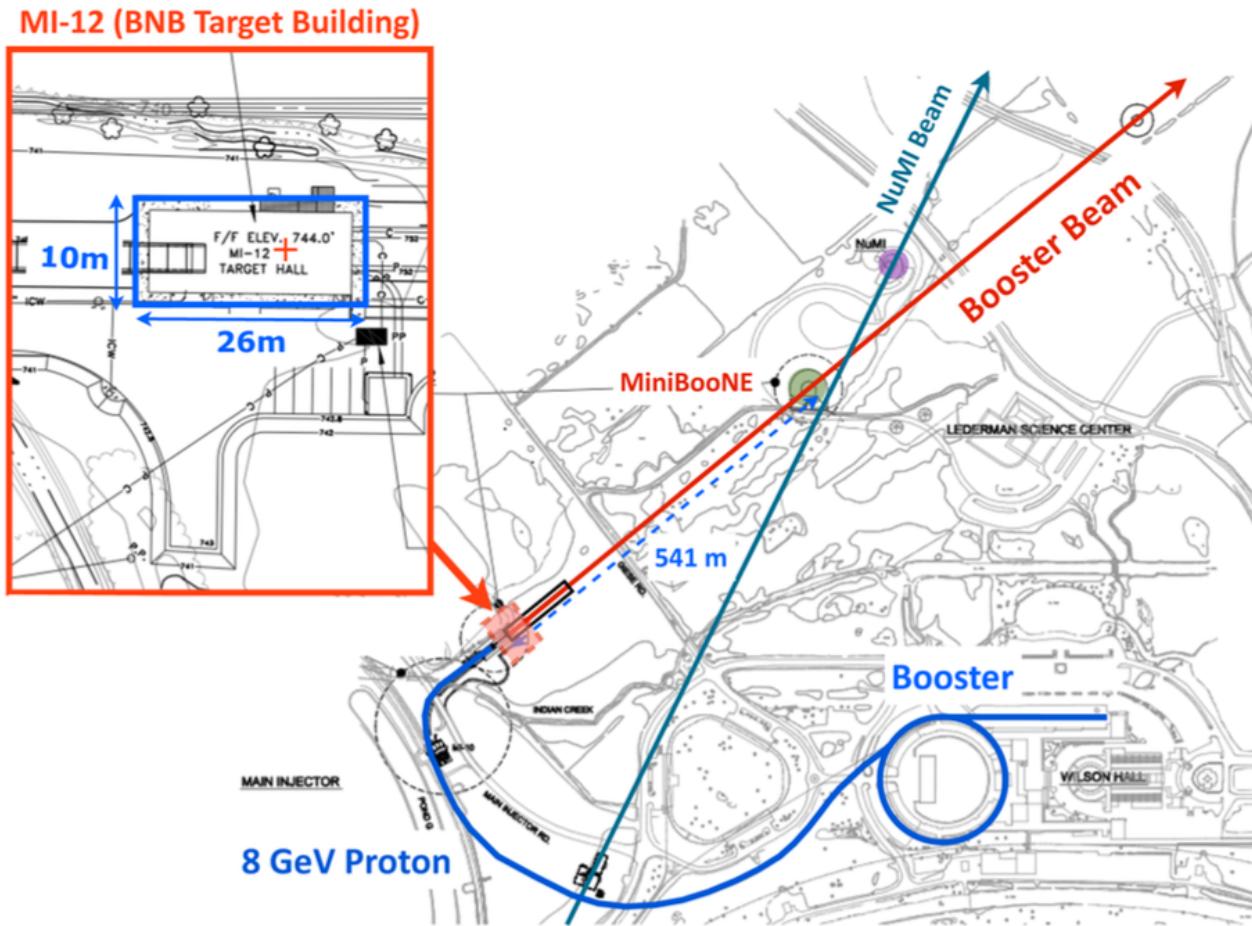
⁵*Virginia Tech, Blacksburg, Virginia 24061, USA*

⁶*North Carolina State University, North Carolina 27695, USA*

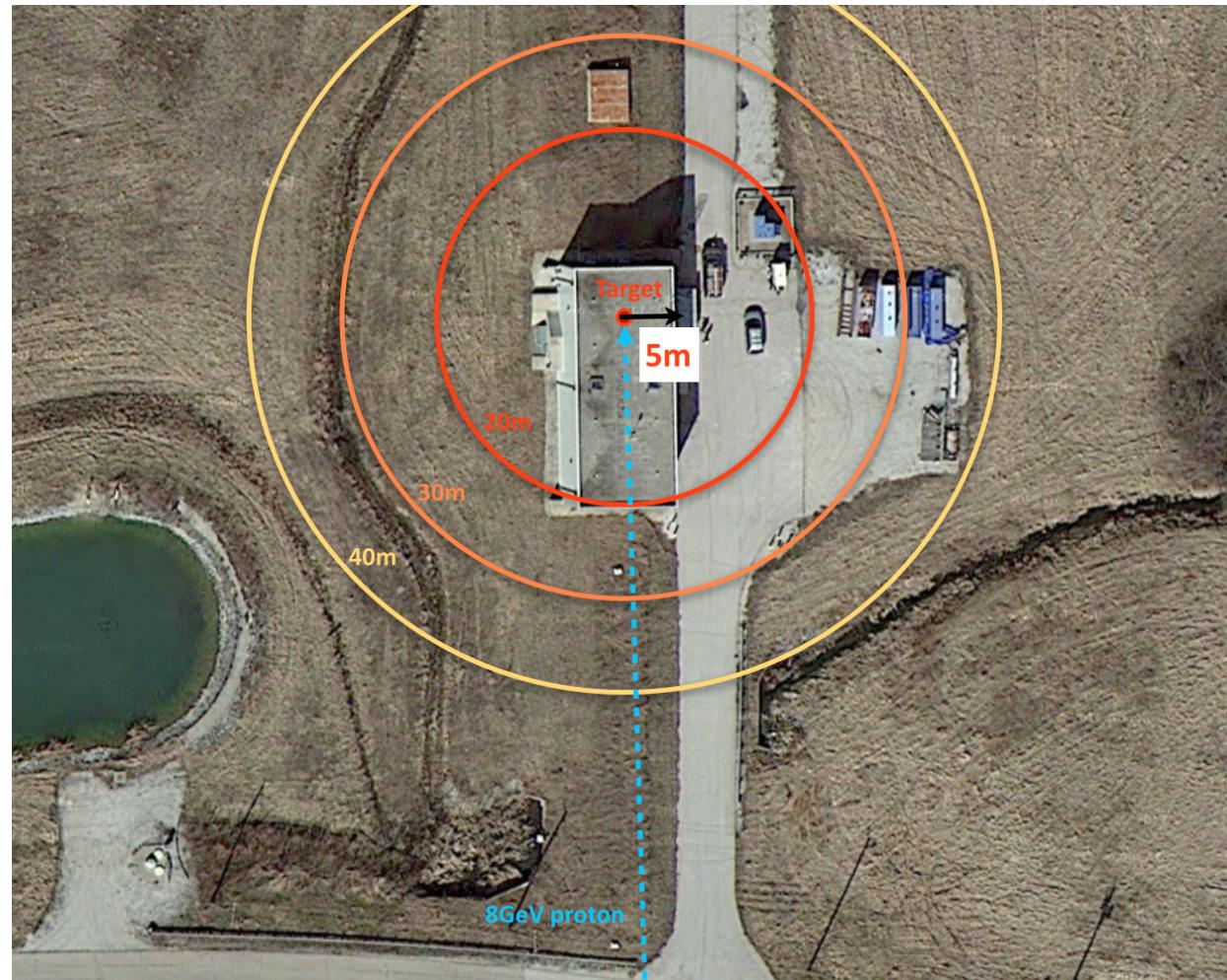
⁷*Duke University, Durham, North Carolina 27708, USA*

(Received 25 November 2013; published 3 April 2014)

Exploit BNB @ Fermilab

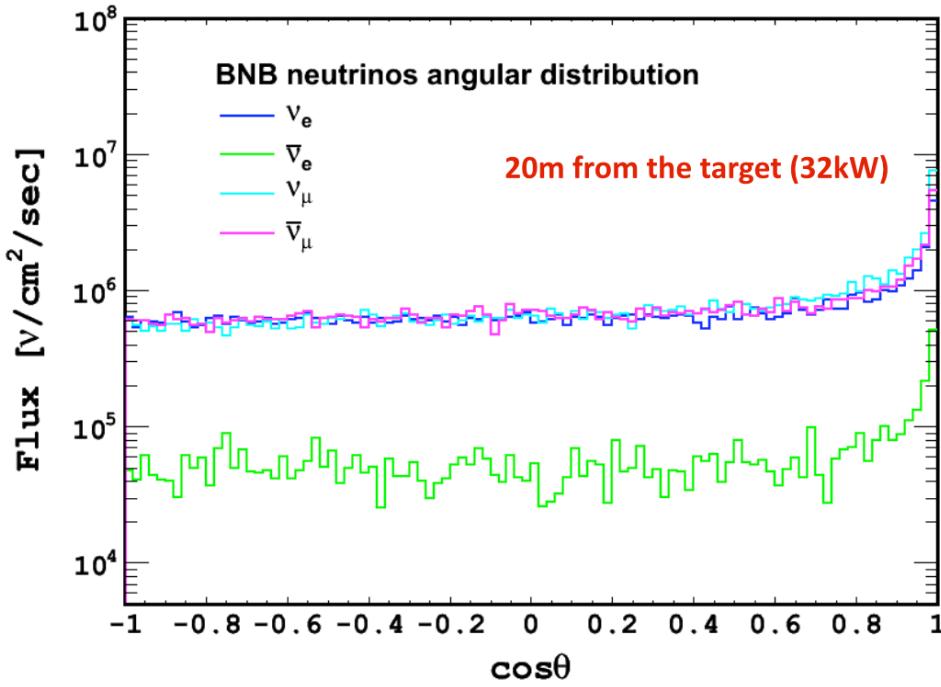


Get Close to the Source



Neutron Production & Angular Distribution

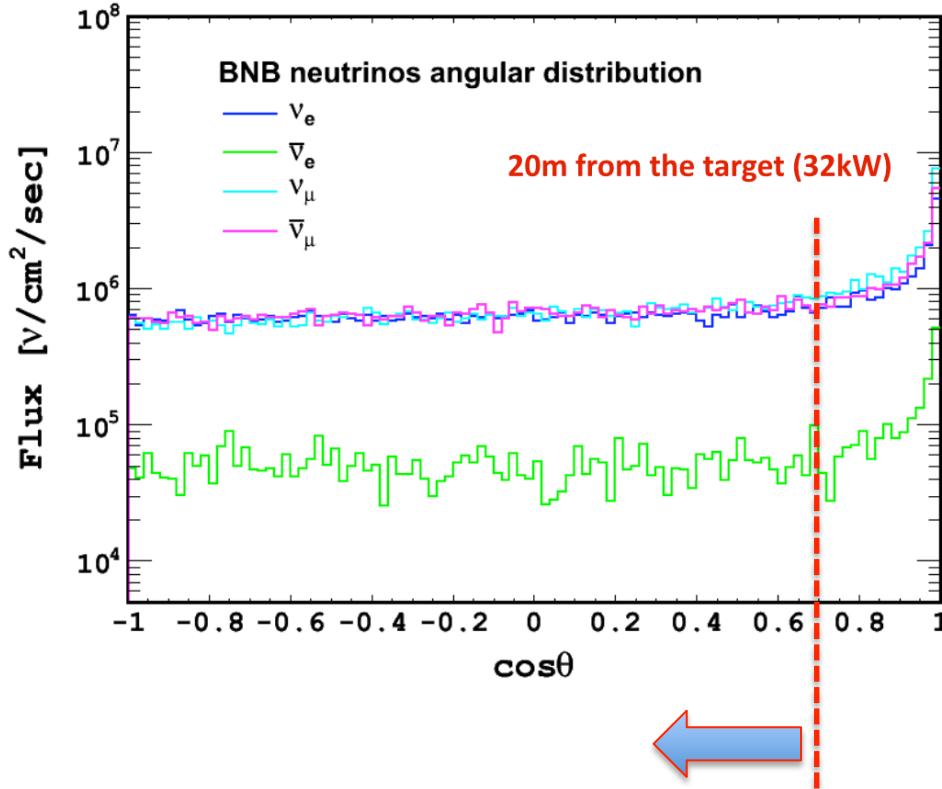
CENNS Collaboration, PRD **89**, 072004 (2014)



Particle	Lifetime (ns)	Decay mode	Branching ratio (%)
π^+	26.03	$\mu^+ + \nu_\mu$	99.9877
		$e^+ + \nu_e$	0.0123
K^+	12.385	$\mu^+ + \nu_\mu$	63.44
		$\pi^0 + e^+ + \nu_e$	4.98
		$\pi^0 + \mu^+ + \nu_\mu$	3.32
K_L^0	51.6	$\pi^- + e^+ + \nu_e$	20.333
		$\pi^+ + e^- + \bar{\nu}_e$	20.197
		$\pi^- + \mu^+ + \nu_\mu$	13.551
		$\pi^+ + \mu^- + \bar{\nu}_\mu$	13.469
μ^+	2197.03	$e^+ + \nu_e + \bar{\nu}_\mu$	100.0

Neutron Production & Angular Distribution

CENNS Collaboration, PRD **89**, 072004 (2014)

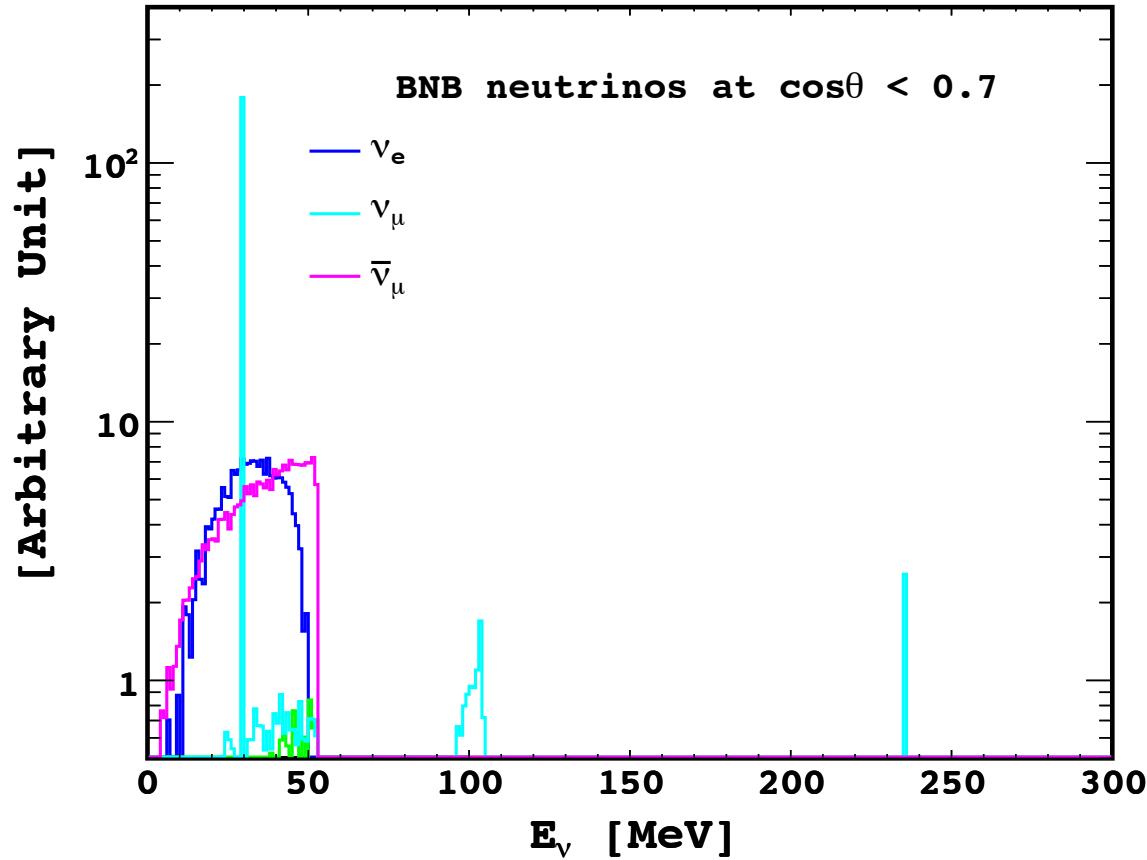


$$E_\nu < \frac{1}{R_N} \simeq 50 \text{ MeV} \text{ to satisfy coherence condition}$$

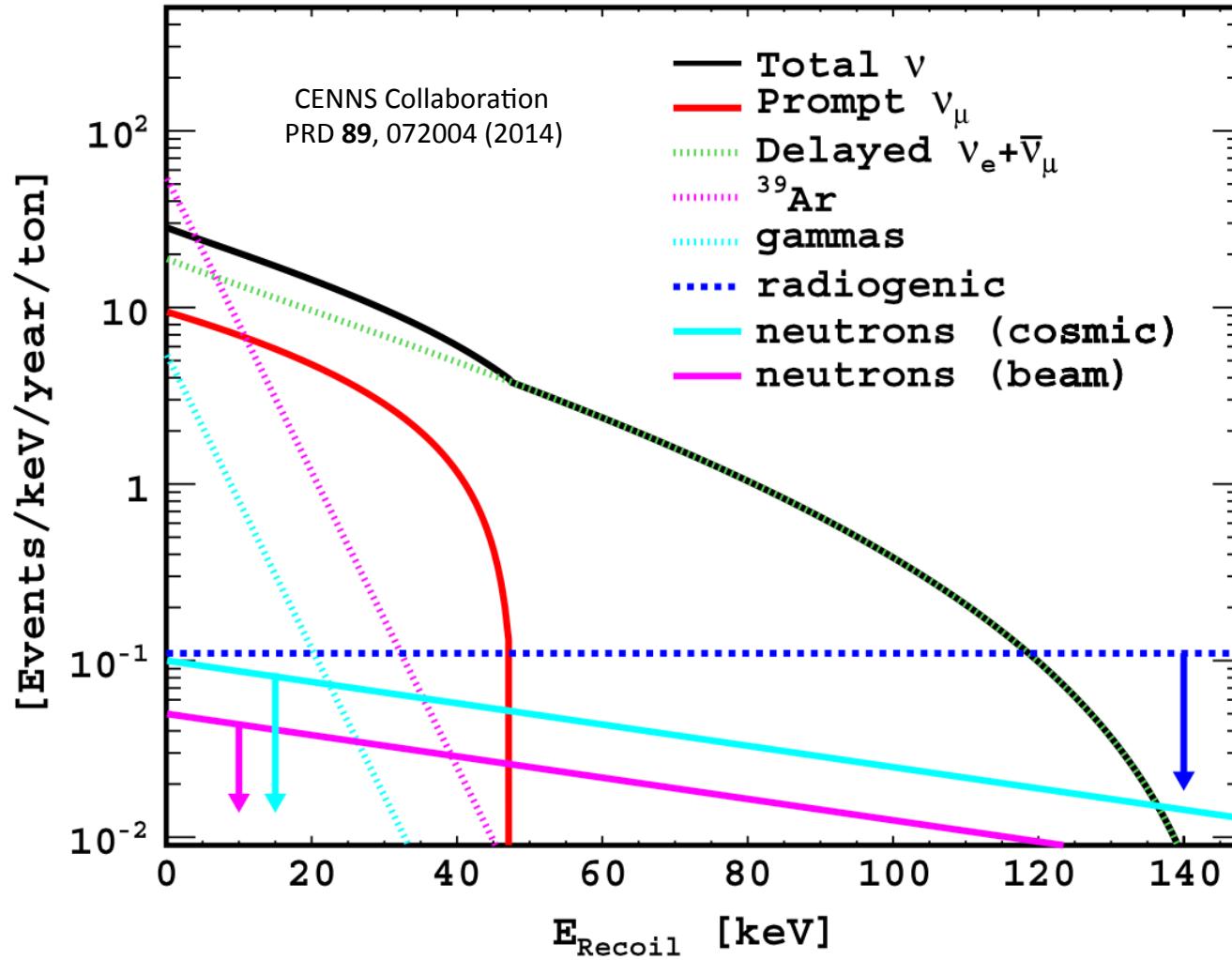
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Off-Axis Neutrinos at Fermilab BNB

CENNS Collaboration, PRD **89**, 072004 (2014)

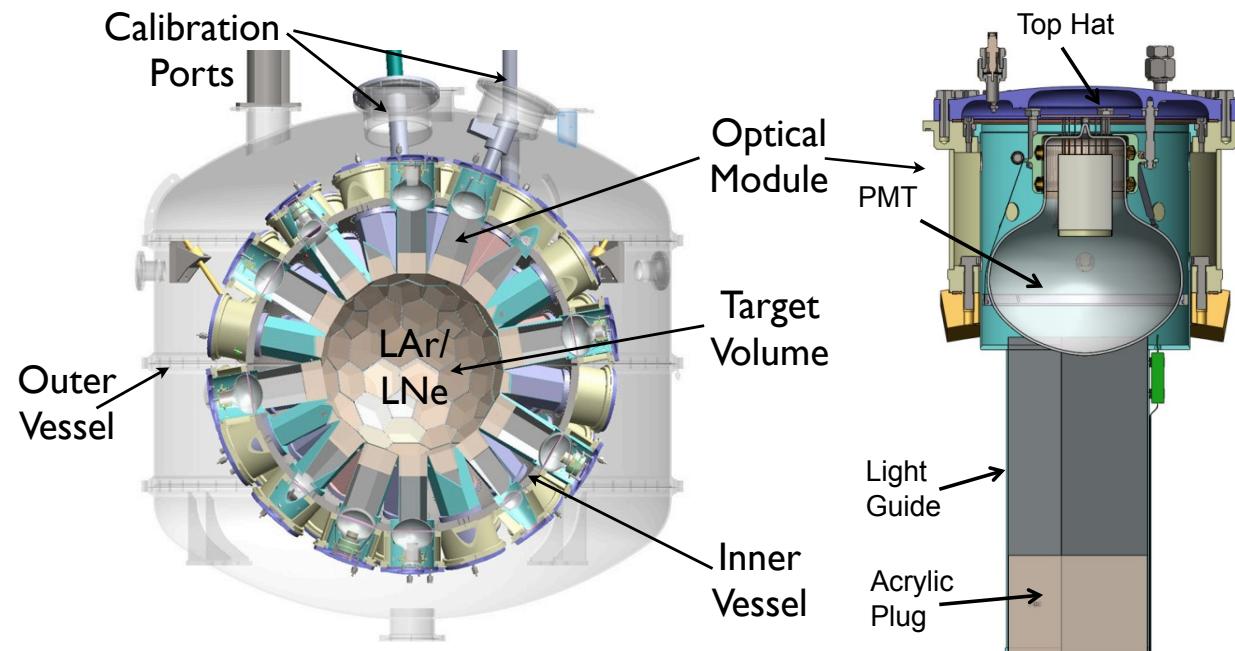


Signals & Background in “tonne-year” LAr Exposure



Consider MiniCLEAN at BNB in 1'rst Generation Experiment

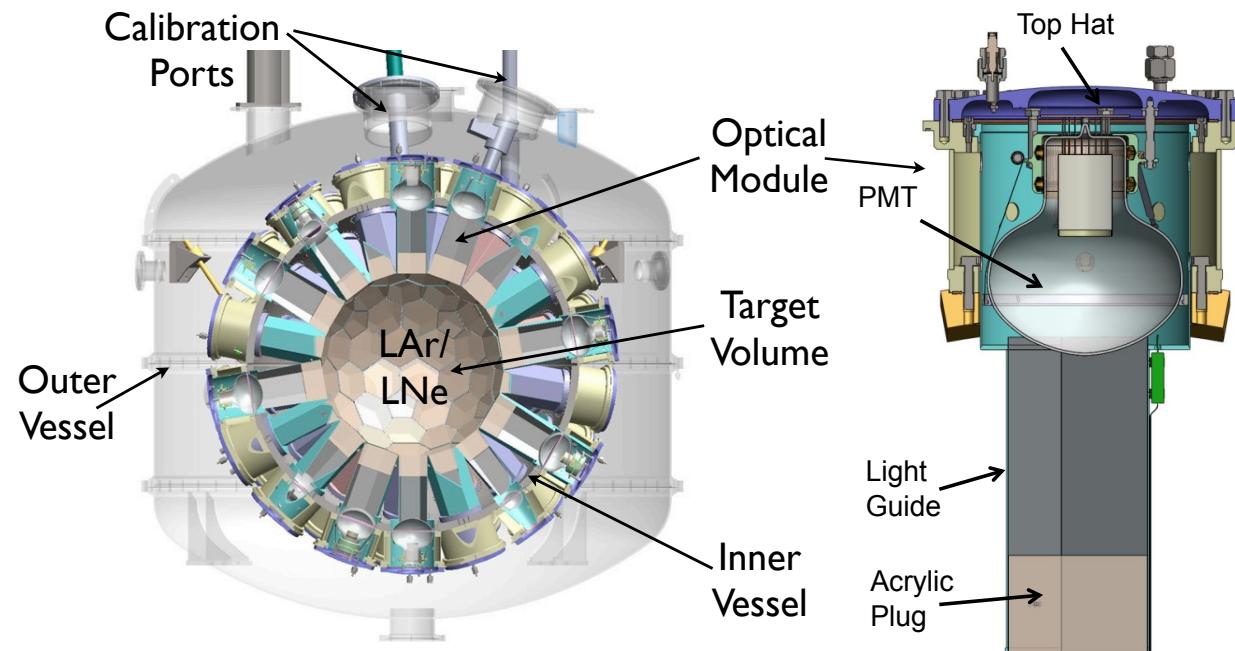
- 4π coverage to maximize light-yield at threshold ...
 - 3D Position Reconstruction
 - Particle-ID via Pulse-Shape Discrimination
- “Cold” design allows both LAr & LNe
- No electric fields ... PMTs only active component ...



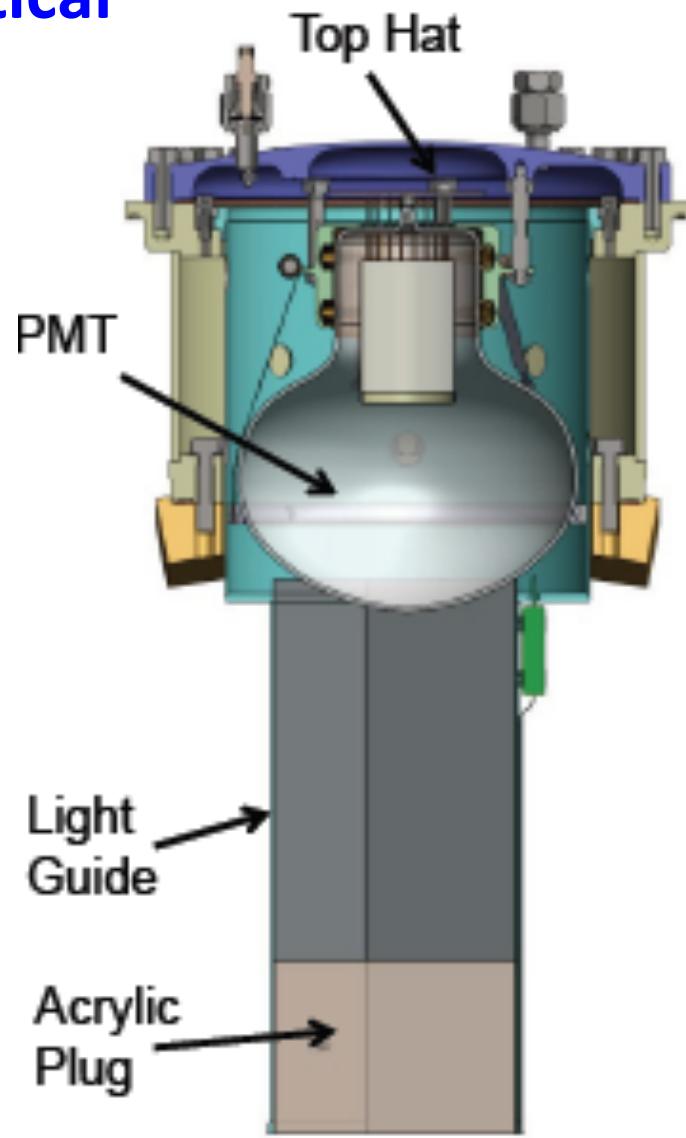
AH, arXiv:1110.1005

Consider MiniCLEAN at BNB in 1'rst Generation Experiment

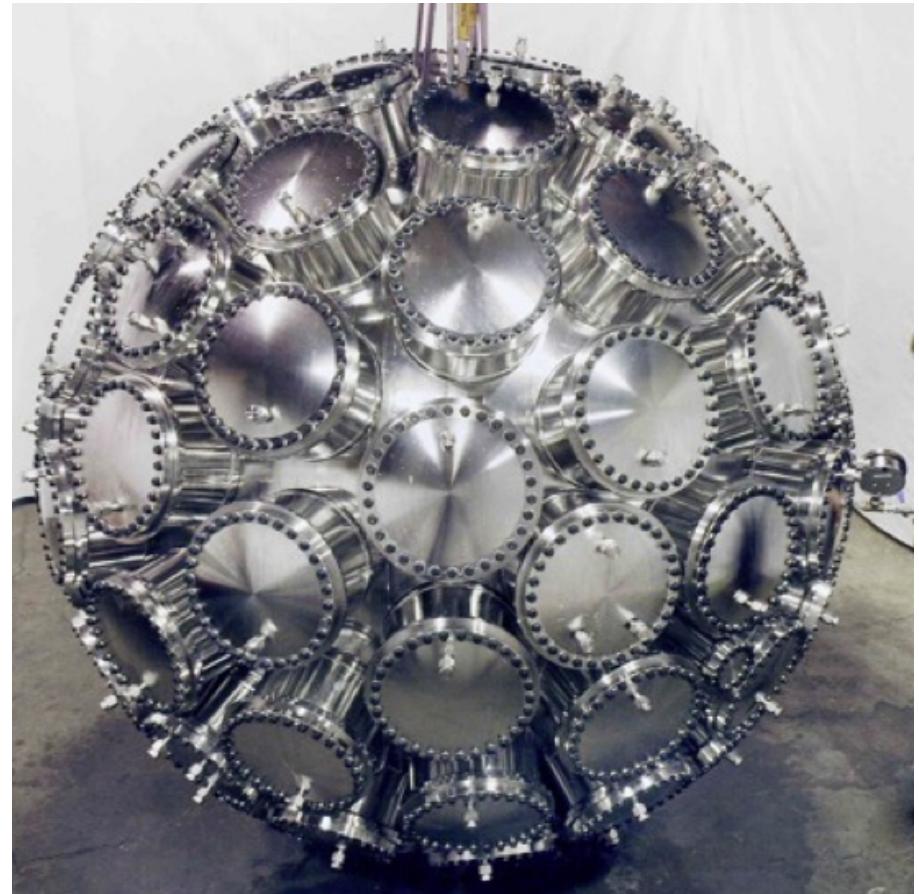
- 4π coverage to maximize light-yield at threshold ...
 - 3D Position Reconstruction
 - Particle-ID via Pulse-Shape Discrimination
- “Cold” design allows both LAr & LNe ... **500 kg Target**
- No electric fields ... PMTs only active component ...



MiniCLEAN Optical Modules



MiniCLEAN Inner Vessel



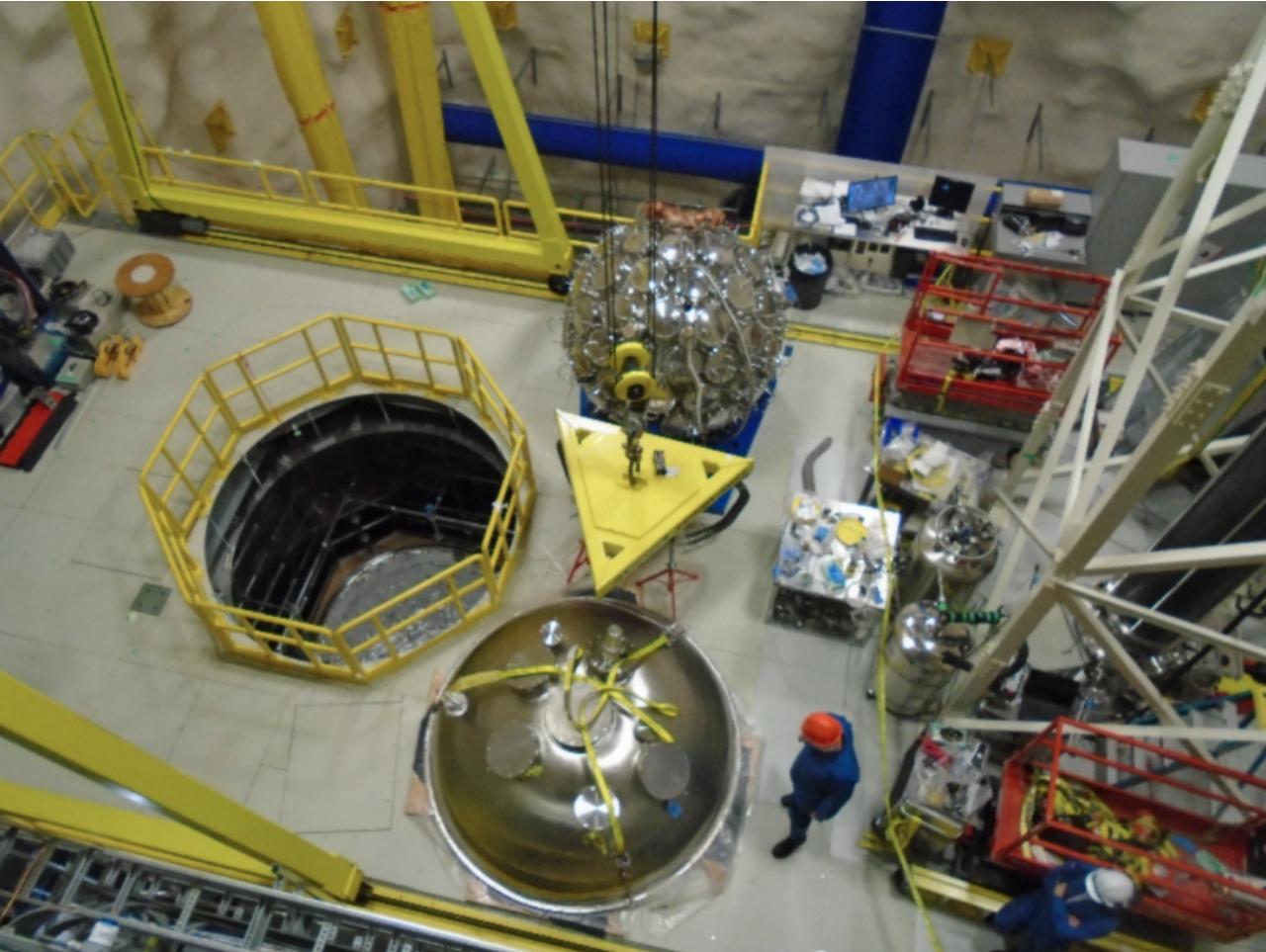
MiniCLEAN Radon-Reduced Assembly



MiniCLEAN Inner Vessel Assembly



MiniCLEAN Installation in SNOLAB Cube Hall

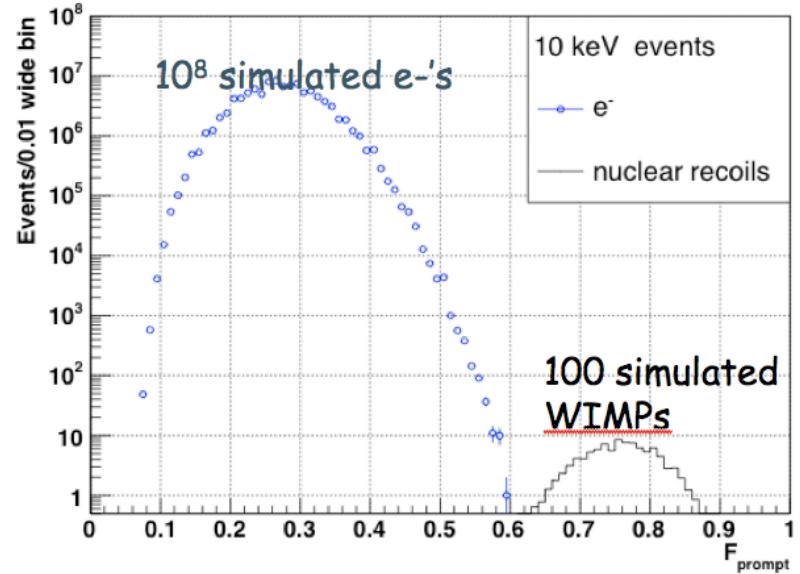
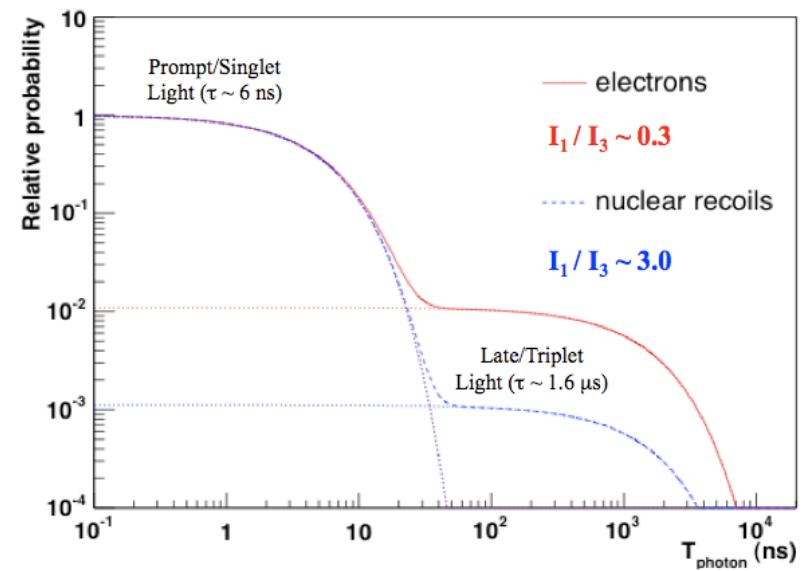
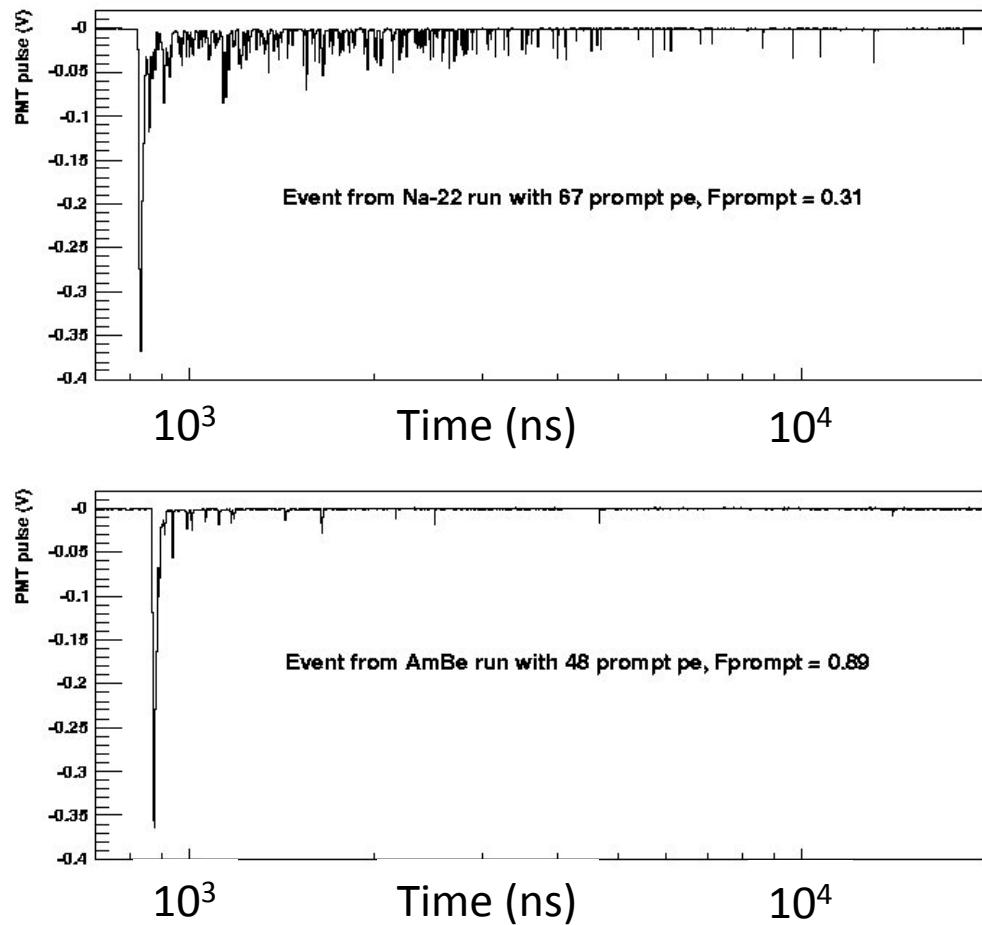


MiniCLEAN Installation in SNOLAB Cube Hall

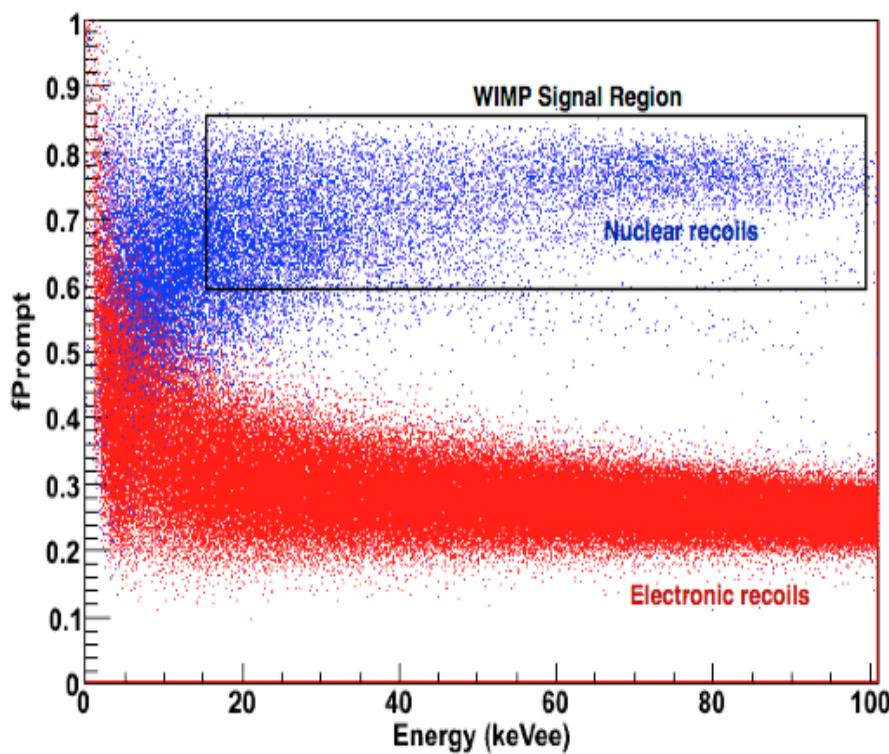


Pulse-Shape Discrimination in LAr

Example Pulses from DEAP-0 at LANL

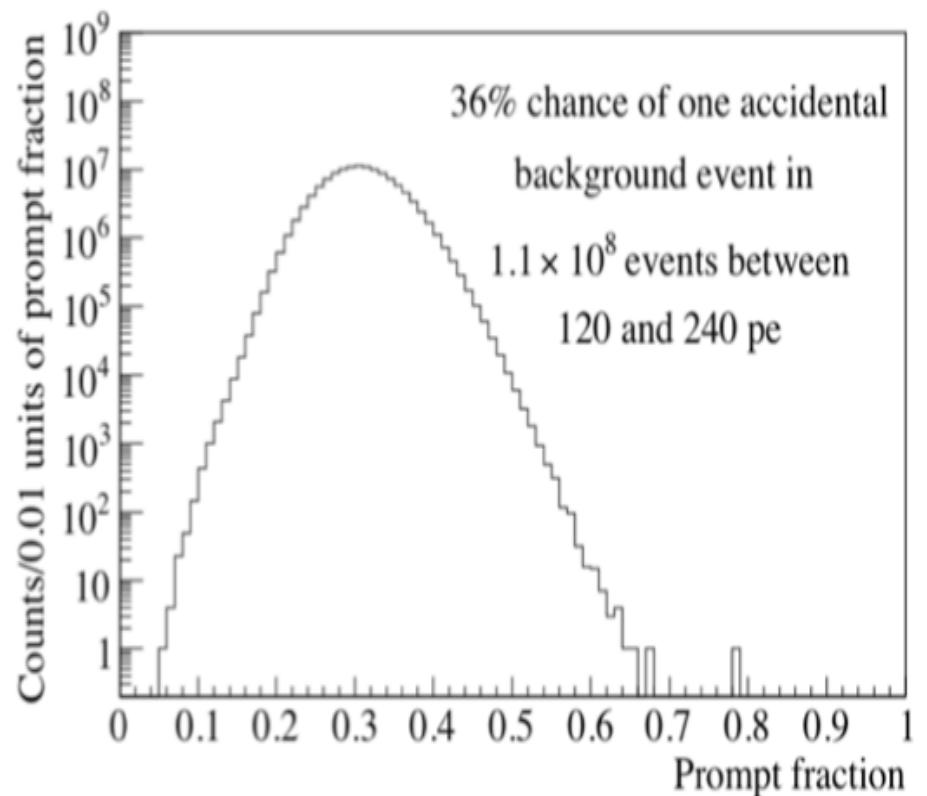


microCLEAN



Phys. Rev. C78, 035801 (2008)

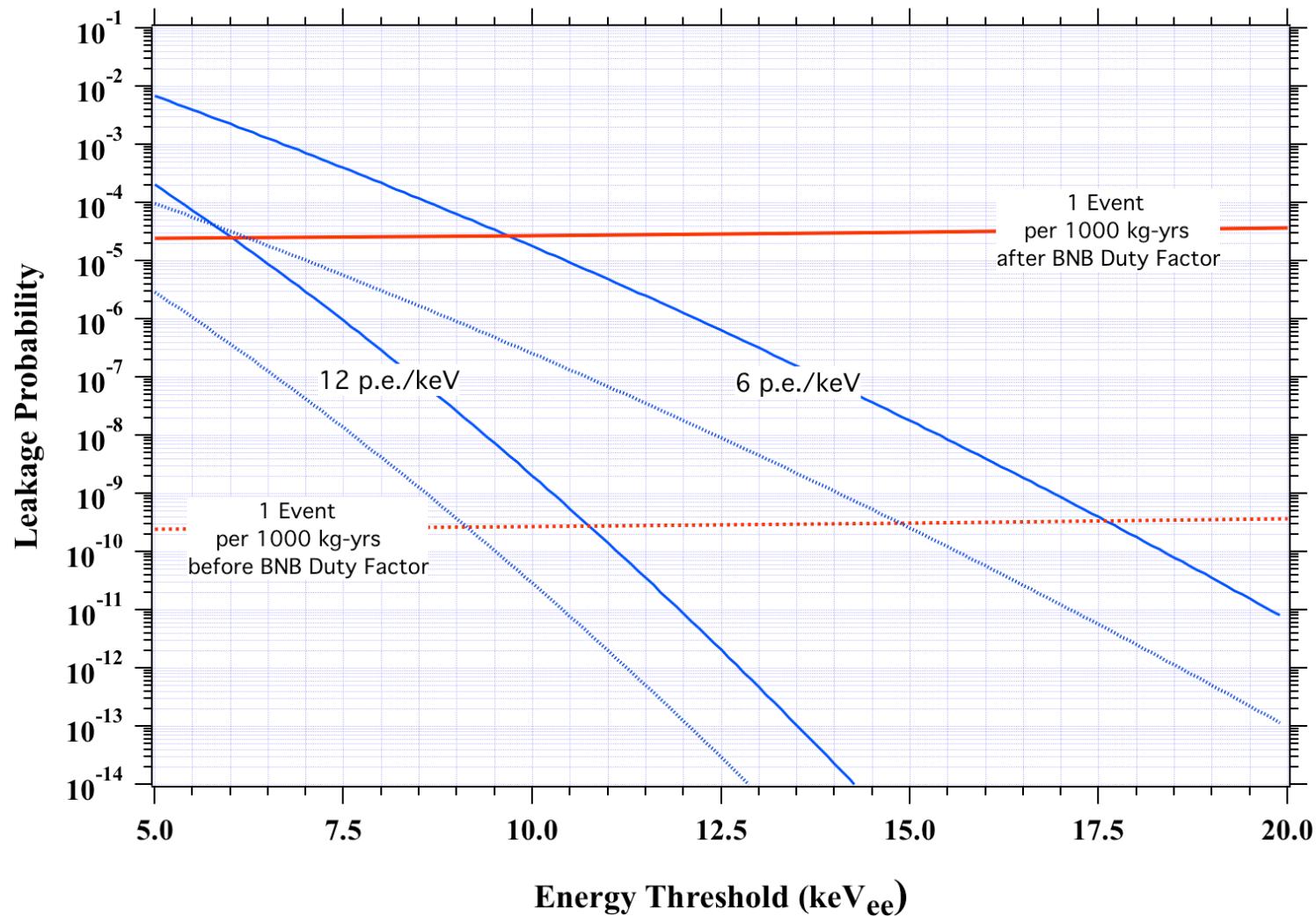
DEAP-1



arXiv:0904.2903 (2009)

TAUP - 2011

^{39}Ar Background Leakage



Detector Related Nuclear Recoil Background

Source	Production Rate (/ton/year)	Detection Rate (events/ton/year)	$E < 25 \text{ keV}_{ee}$	$12.5 < E < 25 \text{ keV}_{ee}$
PMT(α , n)	66,700	11,340	1520	710
Steel(α , n)	3680	495	65	30
Total(α , n)	70,380	11,835	1585	740
Total(α , n) \times duty factor	3.5	0.6	0.08	0.04
Radon	15,880		7,147 ($25 < E < 100 \text{ keV}_{nr}$)	
Radon \times duty factor	0.8			0.36

CENNS Collaboration
PRD **89**, 072004 (2014)

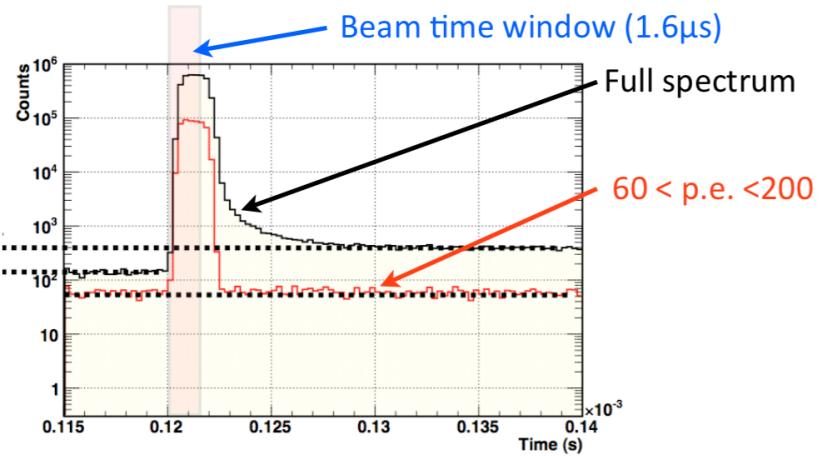
Detector Related Nuclear Recoil Background

- ★ The intrinsically low background in MiniCLEAN combined with BNB duty factor allows Usage of full 500 kg LAr target for CENNS measurements.

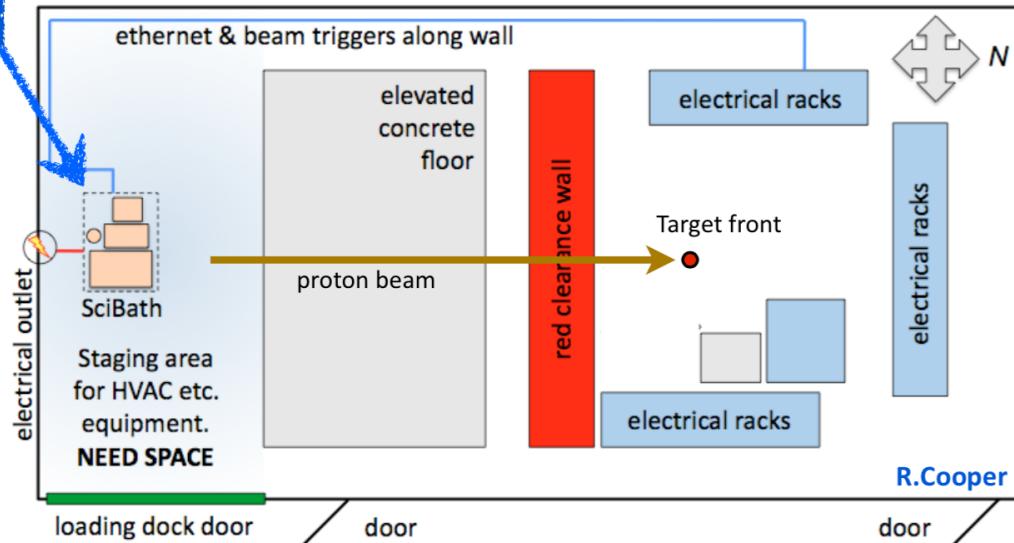
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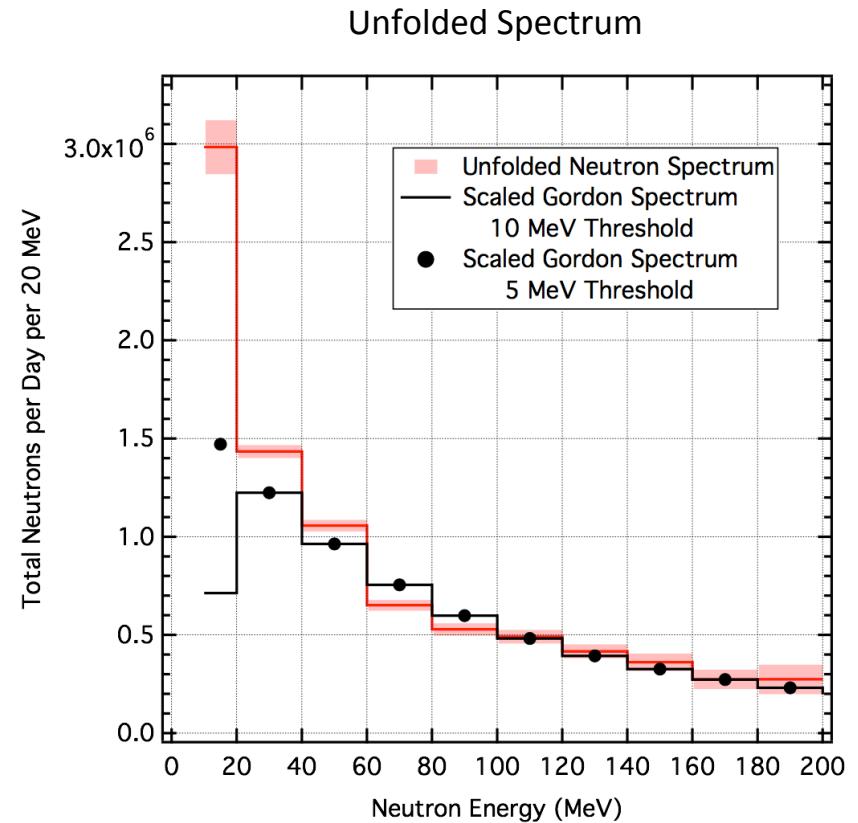
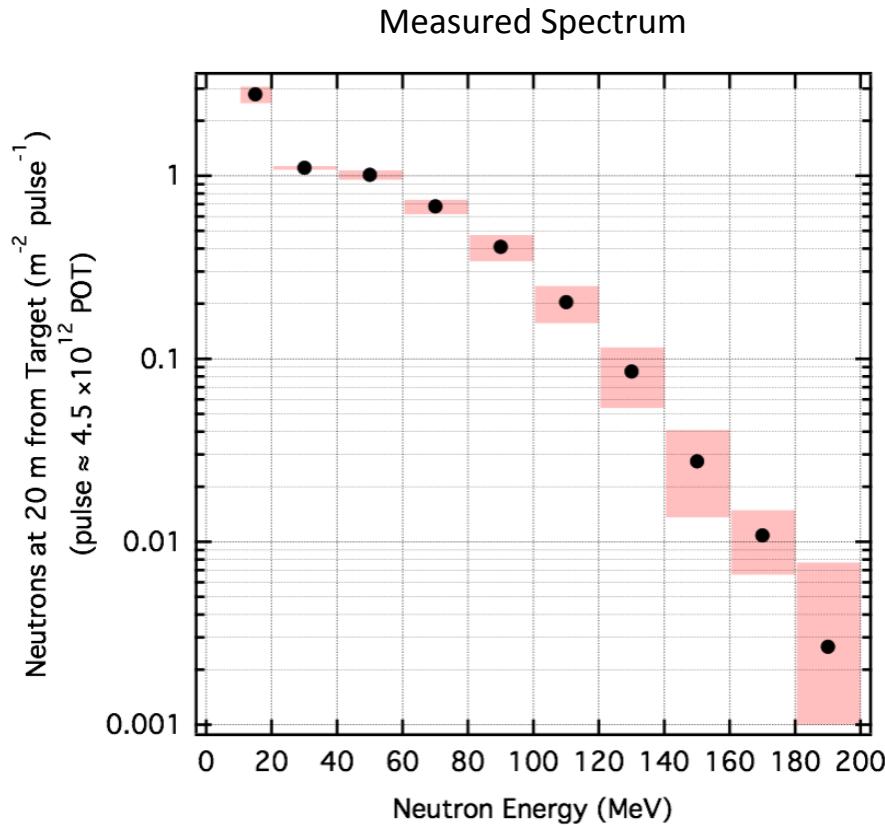
Beam Induced Neutron Background Measured with SciBath



- Detector located in the target building (MI-12 @20m away from the target)
- Pre-beam, in-beam, off-beam backgrounds measurements
- Data taking: Feb~Apr 2012

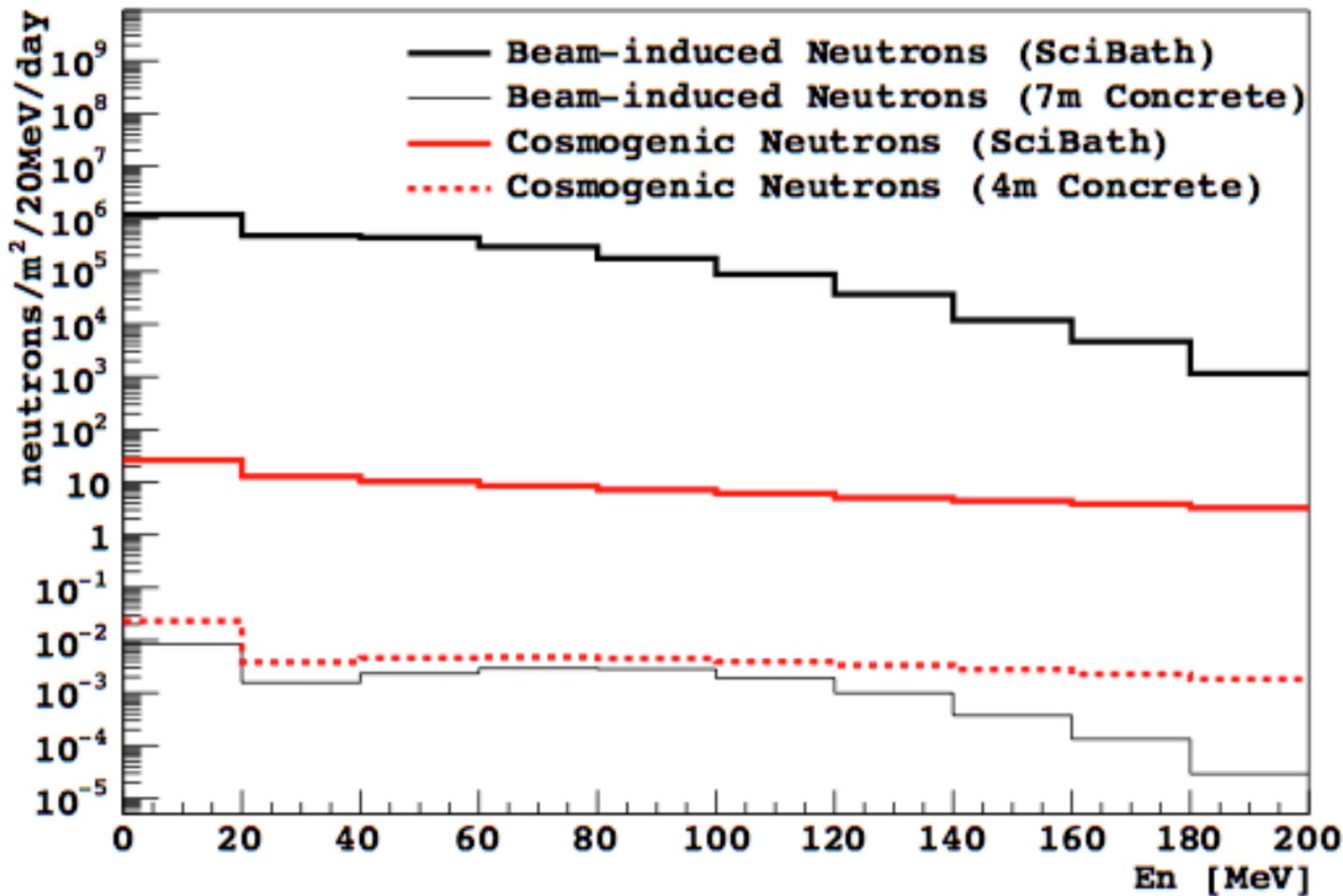


Beam Induced Neutron Backgrounds



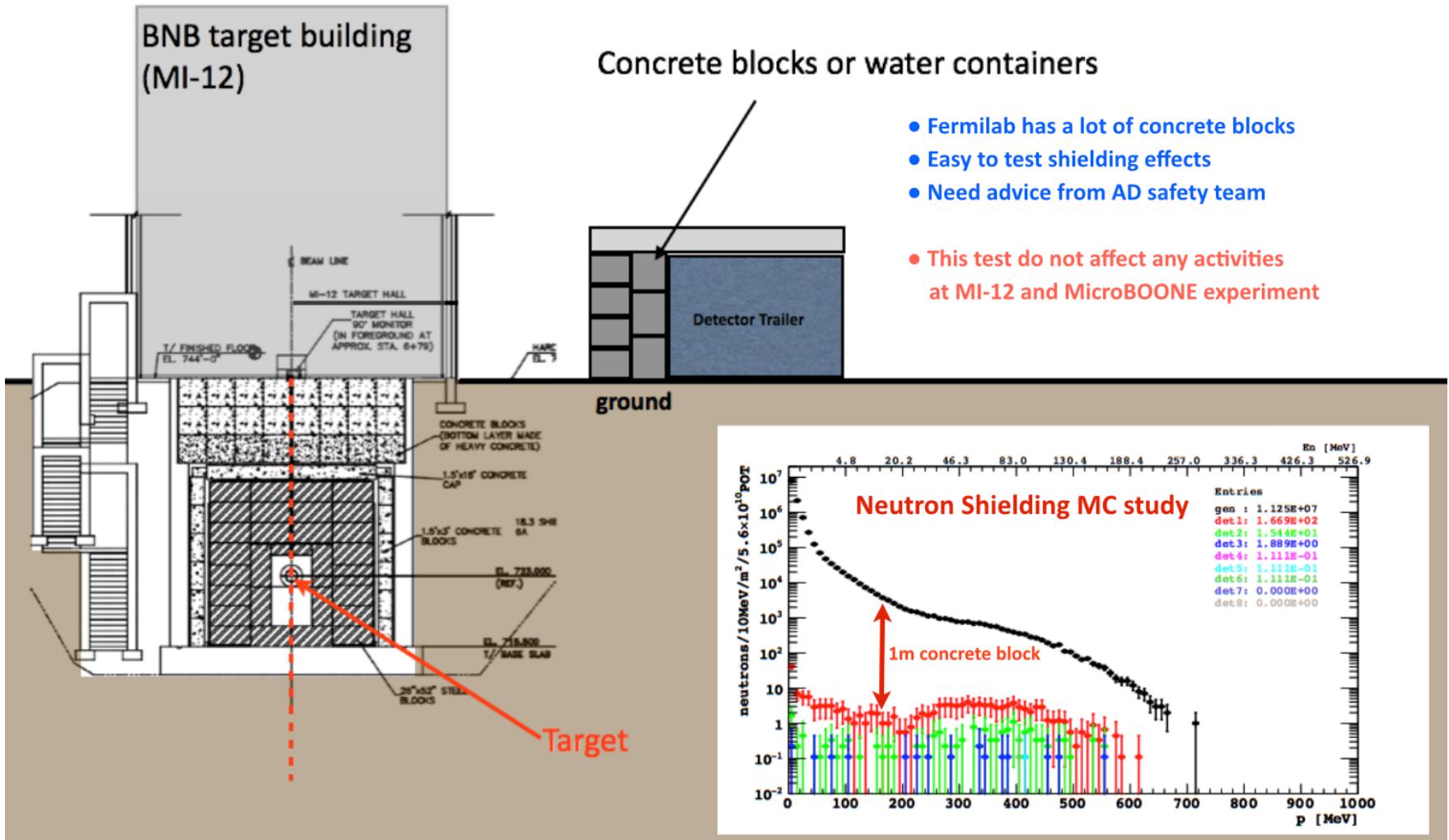
CENNS Collaboration, PRD **89**, 072004 (2014)

MC Study for Shielding Beam Induced Neutrons

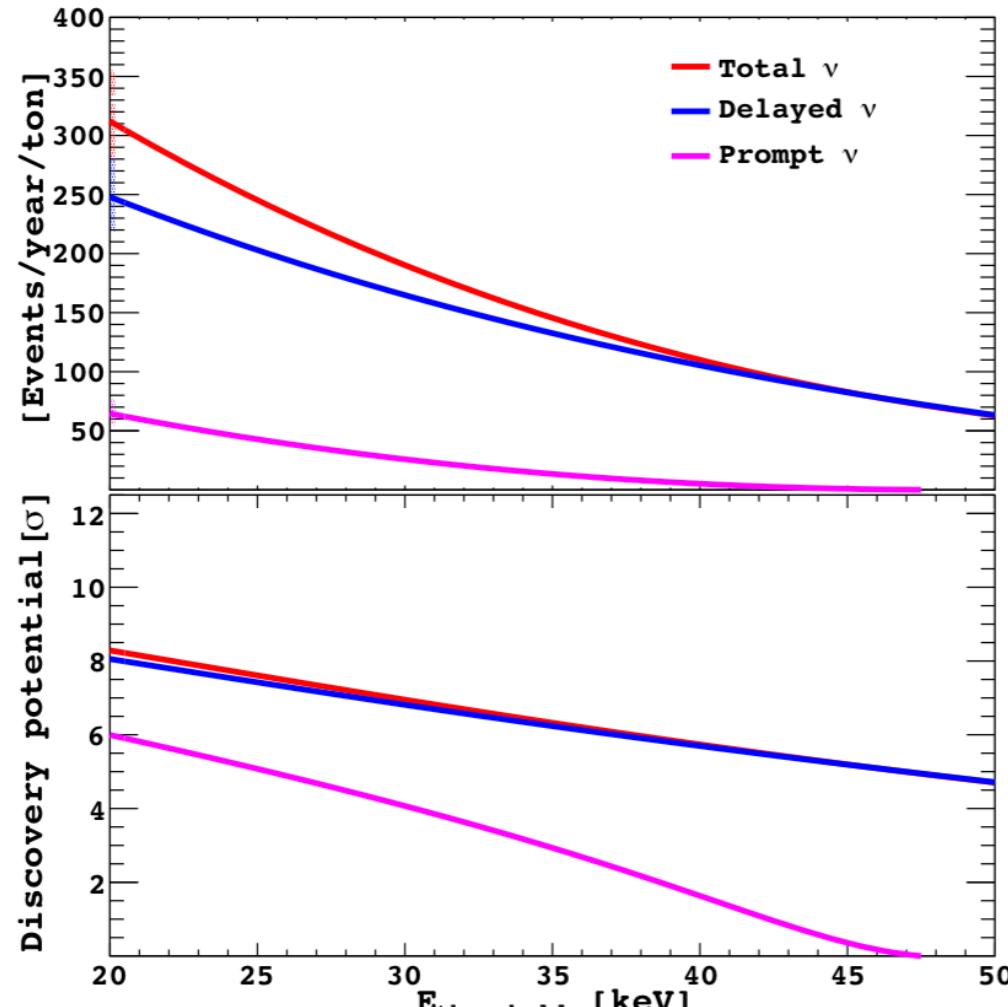


CENNS Collaboration, PRD 89, 072004 (2014)

Planning New Measurements of Beam Induced Neutrons



“Discovery” Potential for CENNS @ BNB



CENNS Collaboration, PRD **89**, 072004 (2014)

Error Budget

	Uncertainty
Neutrino flux	9%
L_{eff} of LAr	7.5%
High-energy neutrinos	< 1%
Beam-induced neutrons	< 1%
Cosmogenic neutrons	< 1%
^{39}Ar and gammas	< 1%
Radiogenic backgrounds	< 1%
<i>Total uncertainty</i>	12%

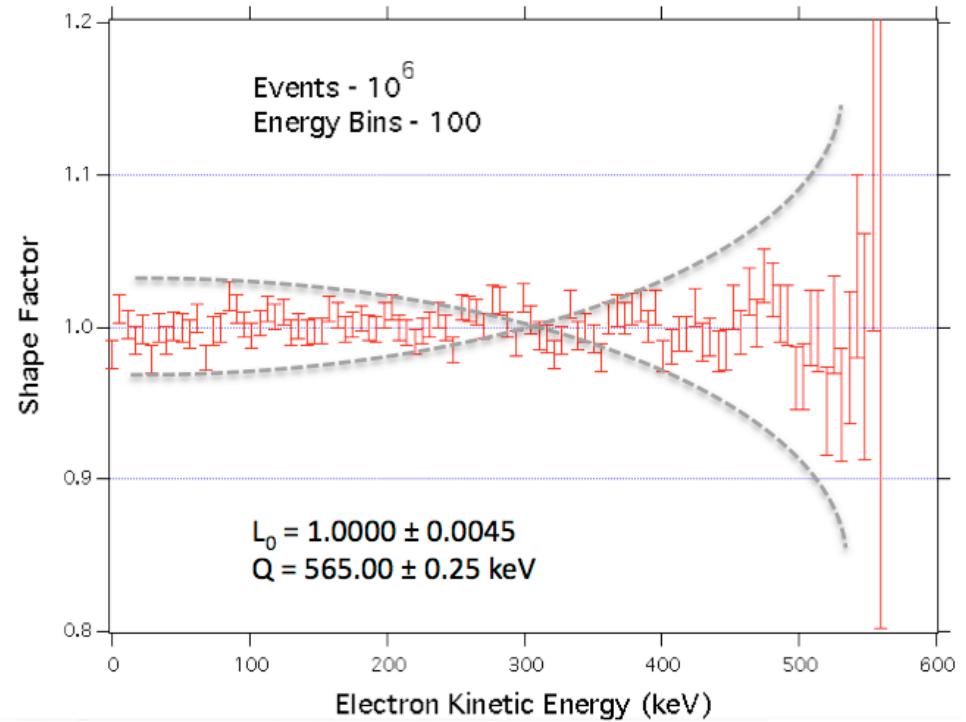
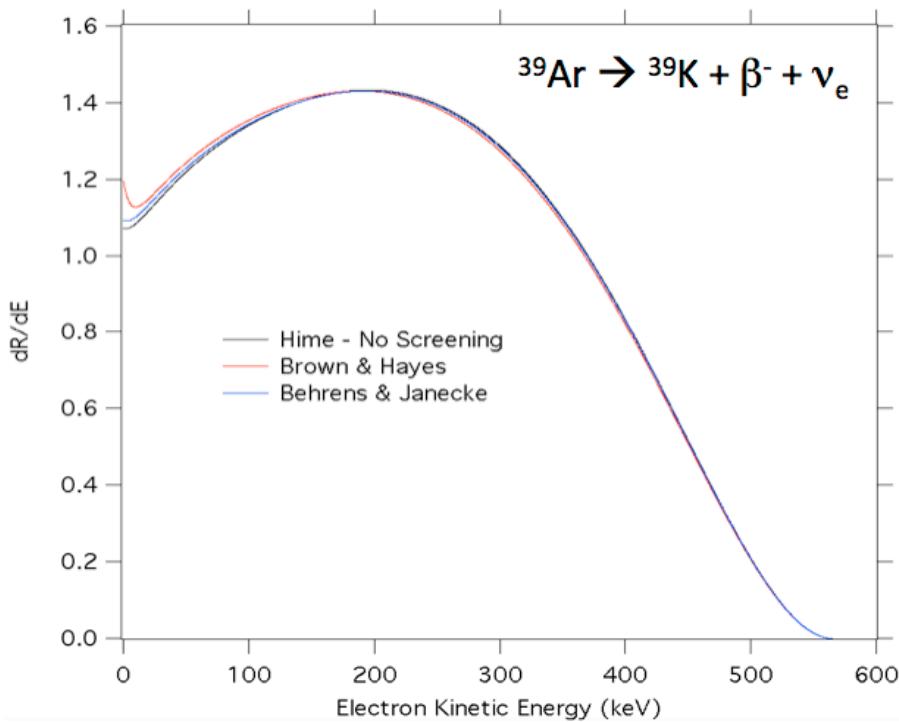
CENNS Collaboration
PRD **89**, 072004 (2014)

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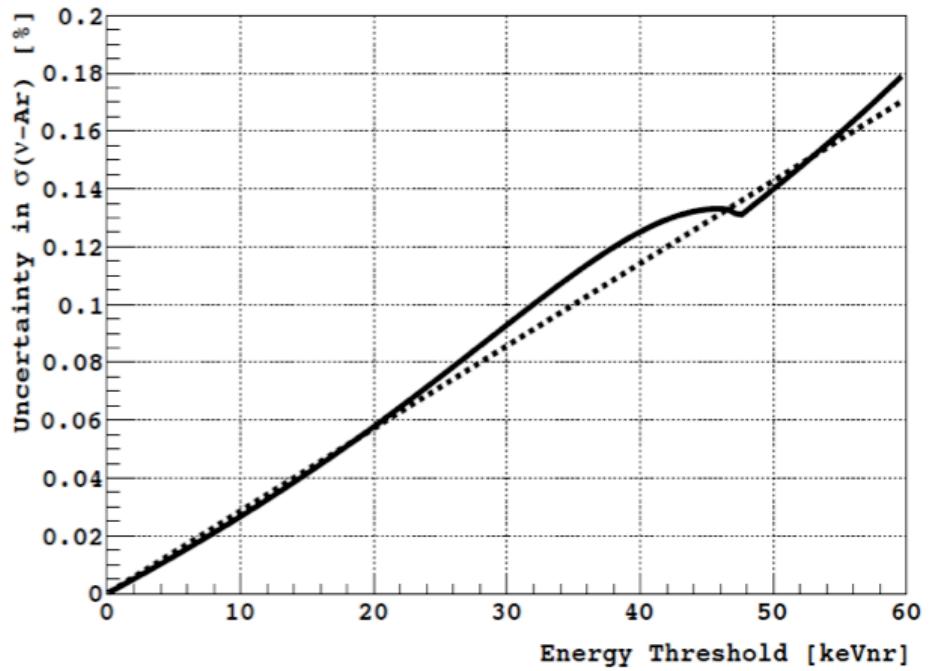
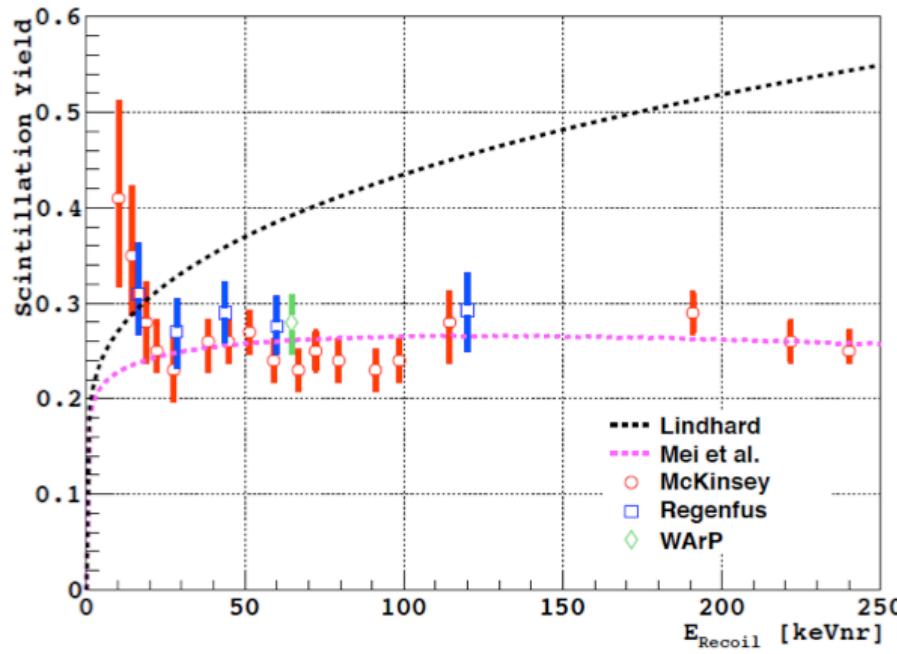
BGNDs
Under Control

Measure Energy Scale with ^{39}Ar Spectrum



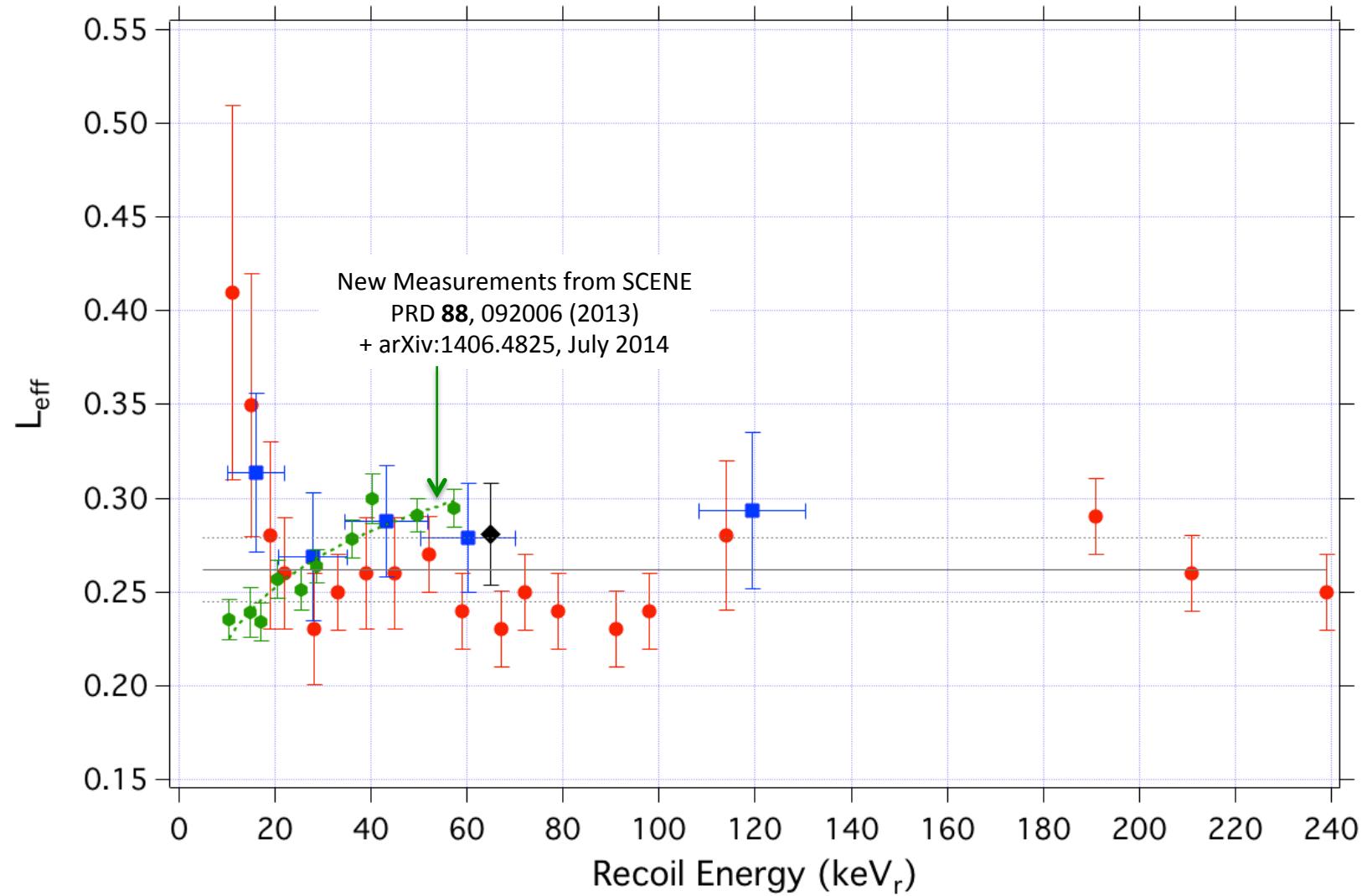
AH, arXiv:1110.1005

Uncertainties from Nuclear Recoil Scintillation Yield



CENNS Collaboration
PRD **89**, 072004 (2014)

Uncertainties from Nuclear Recoil Scintillation Yield



MiniCLEAN Program:

FY15: LAr Commissioning & Science at SNOLAB

FY16: LAr SNOLAB

FY17: Upgrade to LNe and start Science at SNOLAB

FY18: LNe at SNOLAB

FY19: Decommission and start installation at CENNS site

FY20: Start phase-I CENNS Science

Cost Estimates:

~ \$500k to decommission and reinstall

~ \$250k for non-salvageable hardware and reconfiguration

~ \$500k for central water shield and muon veto

~\$1250k (x1.4 = \$1750k)

Infrastructure at FNAL BNB:

- Beam-induced neutron shielding?
- Building?
- Synergy & planning with Captain?

A Perspective

A phased program for CENNS measurements at the Fermilab BNB is both timely and strategic. On the one hand, the existing BNB can provide the low-energy neutrino source to carry out a Phase-I scientific program using the MiniCLEAN detector. It is pertinent to note that the design and construction of the MiniCLEAN detector was at a capital Cost of ~\$10M.

With accelerator upgrades at Fermilab anticipated in the future, the substantial increase in neutrino intensity (following upgrade from ~32 kW to ~1.2 MW) would allow a factor of 6 in statistics and maintaining use of the MiniCLEAN detector. This would poise the community well for a proposal to stage a massive LAr detector at the BNB to exploit CENNS as a new tool for exploring neutrino physics.

Thank You

